Weather-Climate: Reanalysis, Data Assimilation, Observing System Simulation Experiments (OSSE)

Map Meeting

7-9 March 2007

Siegfried Schubert - Science Overview

Ron Gelaro - Data assimilation

Michael Bosilovich - Reanalysis, OSEs

Lars-Peter Riishojgaard - OSSEs

(with contributions from Steven Pawson)

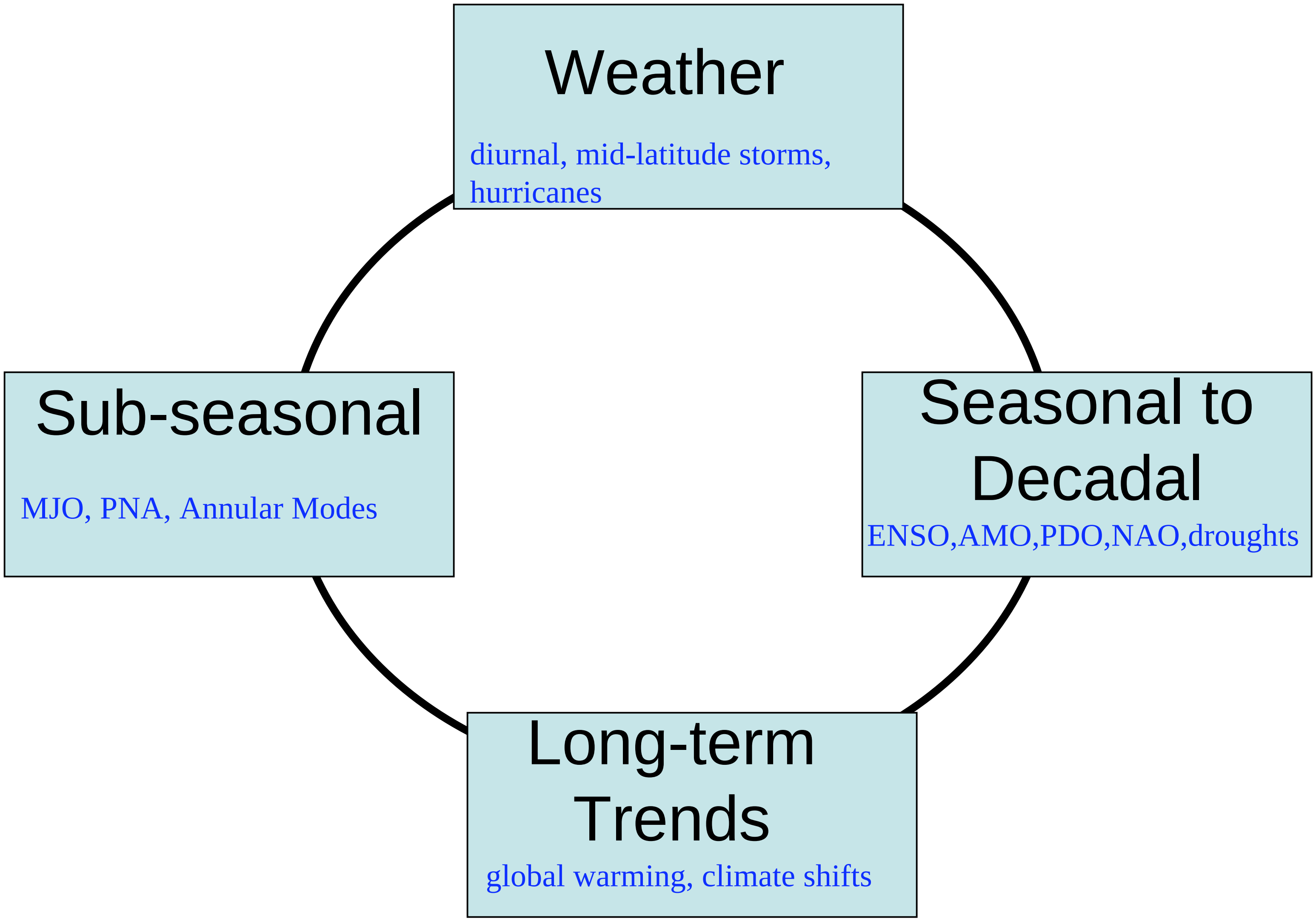
Linking Weather and Climate

Understanding and predicting **regional impacts** of climate variability and change

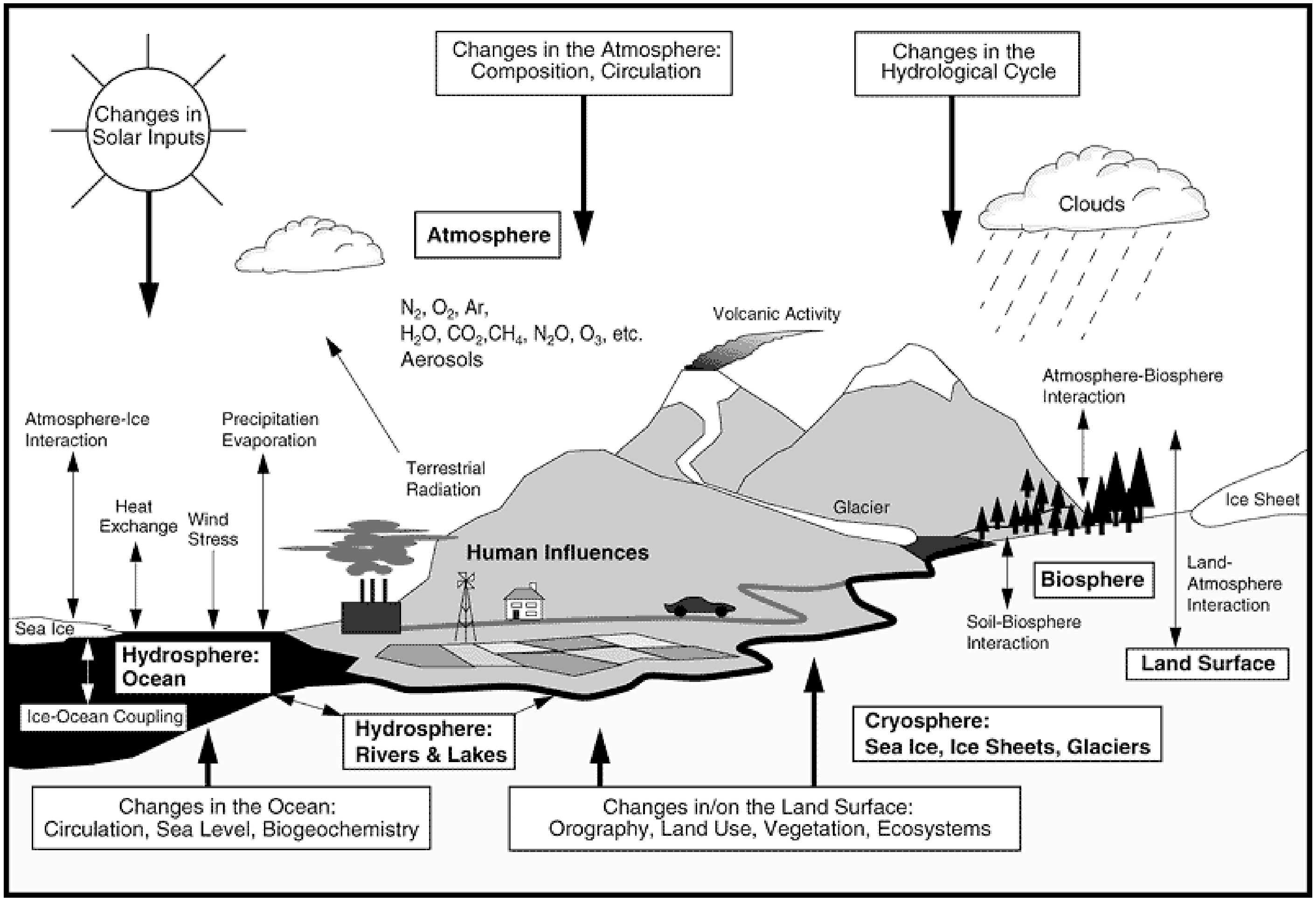
Involves:

- A wide range of space and time scales (“seamless”)
- Remote, local and global-scale processes (“forcing”)

Time Scales/Phenomena



Processes/components

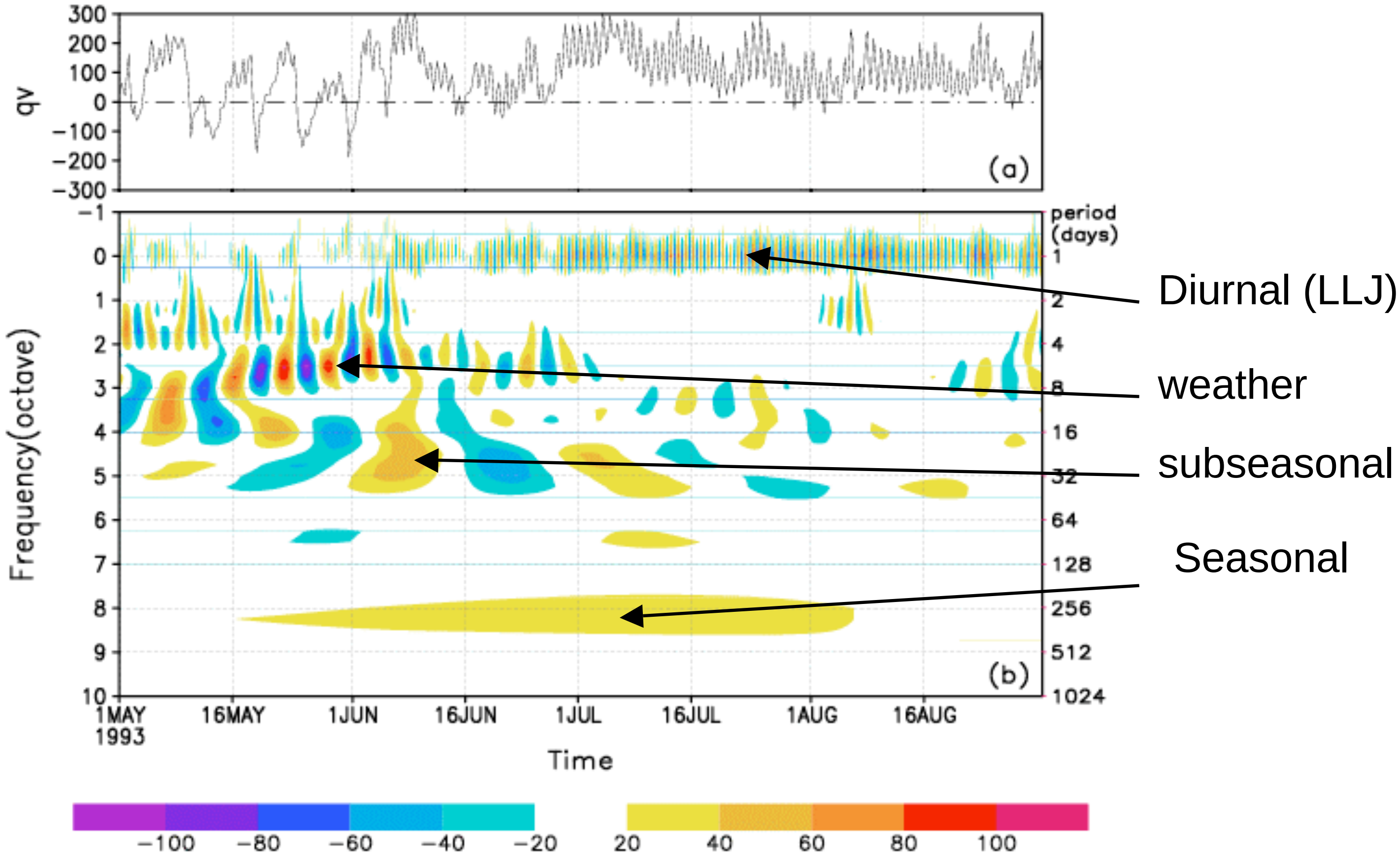


Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows). From Climate Change 2001: The Scientific Basis

Example 1:
US Floods, Droughts

Wavelet Analysis of the Moisture Entering the United States from the Gulf of Mexico

Major flooding: the result of contributions from different atmospheric phenomena/ frequencies as well as preconditioning of the soil



Wavelet analysis of low level northward moisture transport (vq) at 32°N, 97.5°W for May -August of 1993. The top panel is the time series of vq. The bottom panel is the real part of the wavelet transform for each frequency. Units are $(m/s\ g/kg)^2$. From Schubert, Helfand, and Wu 1998.

Diurnal variability: LLJ --> moisture transport, boundary layer convergence, precipitation (also links to mesoscale propagating systems)

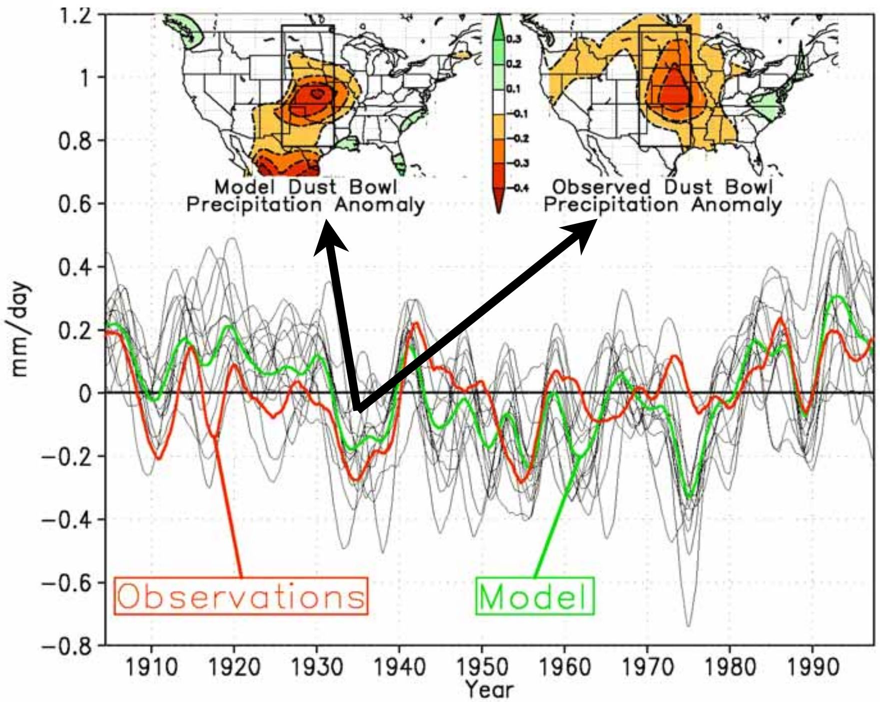
Weather: disrupts diurnal cycle, taps moisture in a “broadened” LLJ

Subseasonal: nature unclear (slow moving weather systems)

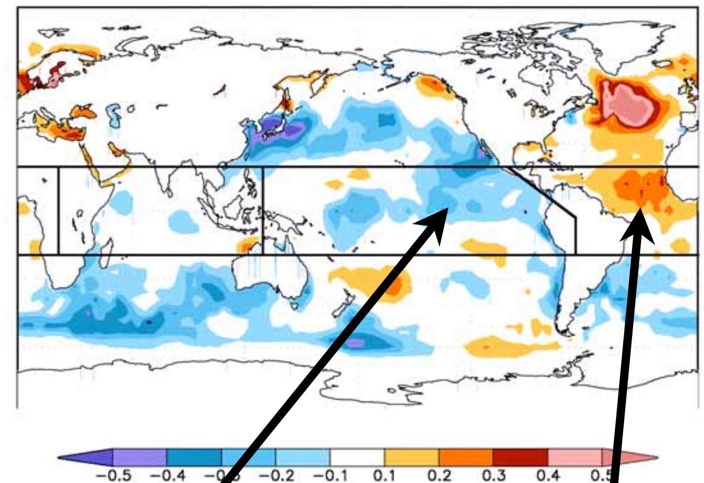
Seasonal and longer: preconditioning of soil, links to Pacific SST, extension of moisture transport associated with Atlantic subtropical anticyclone

Unraveling the Causes of Past Droughts

Dust Bowl Precipitation Anomalies



1930s SST Anomalies produced the Dust Bowl:



A cool tropical Pacific reduced the number of Pacific storms entering the U.S.

A warm Atlantic reduced the transport of warm season moisture into the Great Plains.

Land/atmosphere feedbacks during the summer amplified the drought

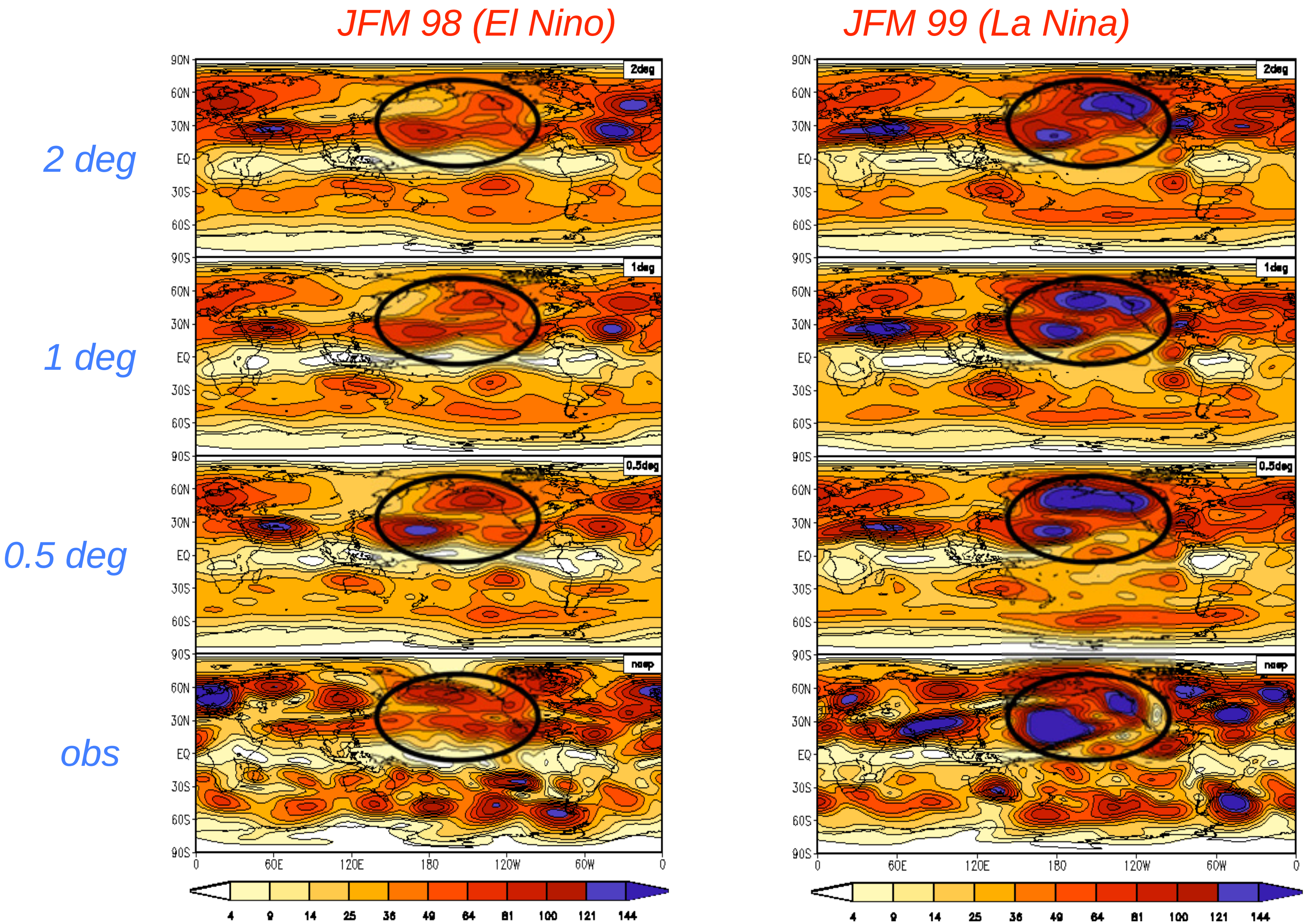
Example 2:

US Weather Variability and Extreme Events

ENSO Impact on Subseasonal Variability

Y. Chang et al.

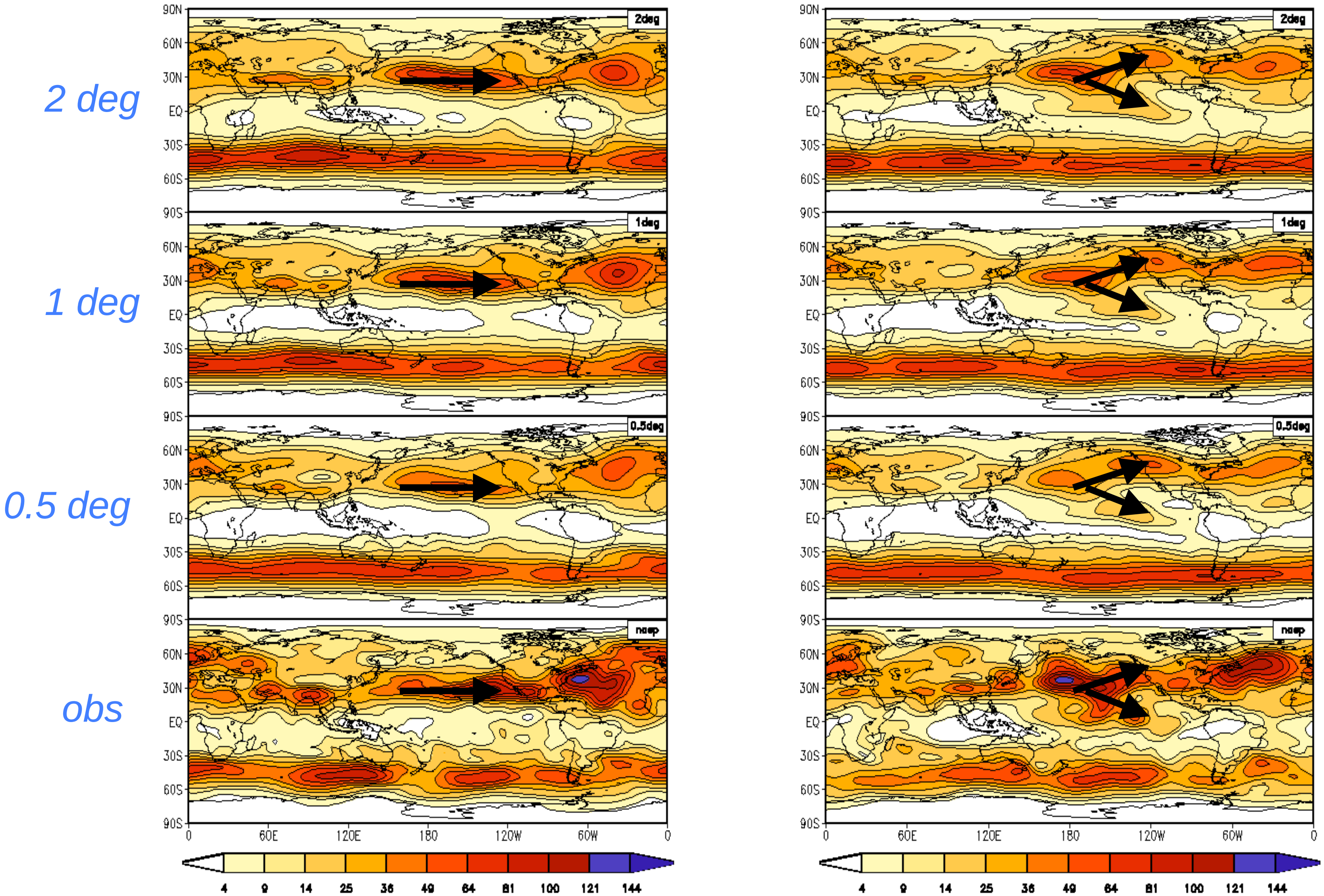
200mb Ψ wind variability (10-30 days)



ENSO Impact on Weather Variability

200mb Ψ wind variability (2-6 days)

JFM 98 (El Nino) | JFM 99 (La Nina)



ENSO --> Stationary Waves

--> Stability of the east Asian jet

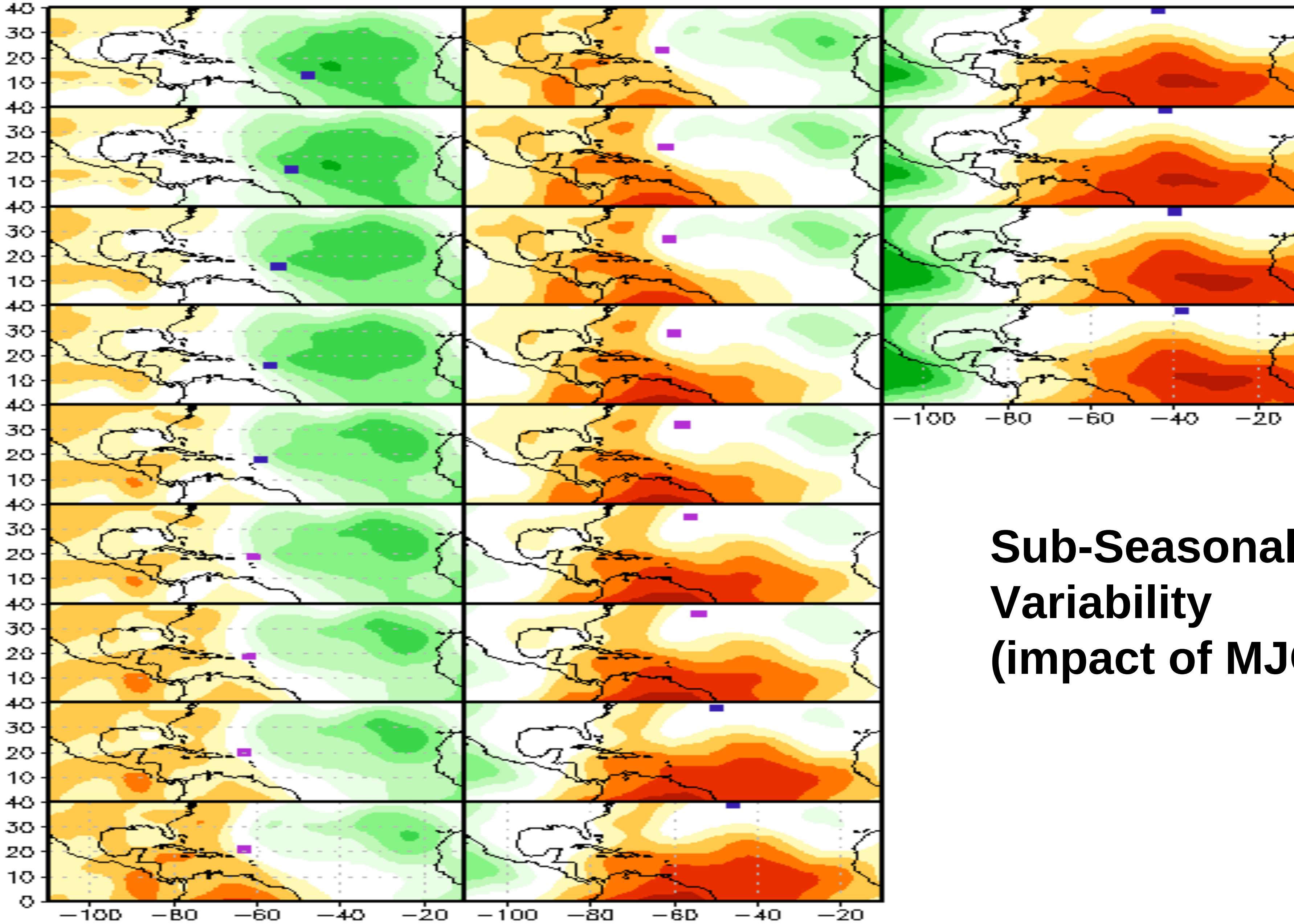
--> Subseasonal variability

--> changes in weather (tracks, extremes, etc.)

Example 3:

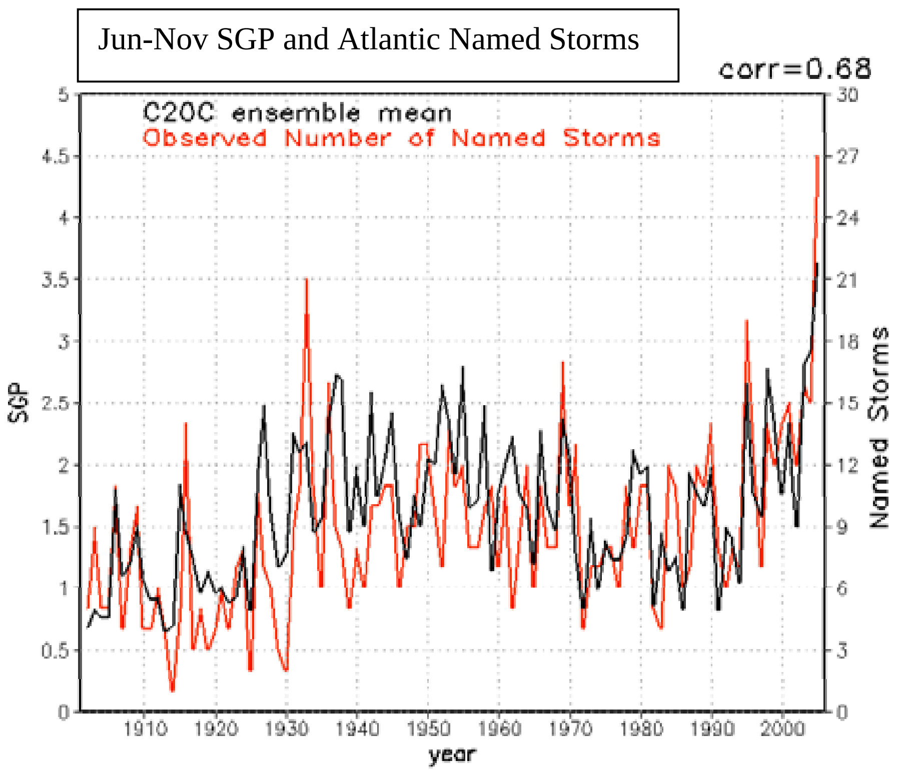
Hurricanes

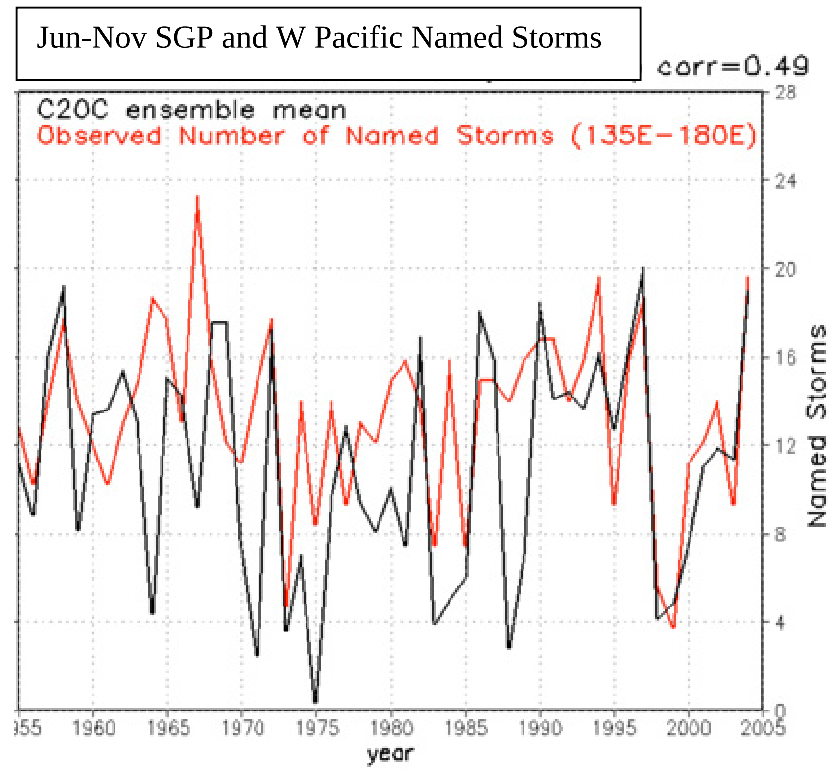
Velocity Potential at 200 hPa (20 - 90days) and Erika (1997)



Sub-Seasonal Variability (impact of MJO)

The number of calendar year named tropical storms compared with the June-November storm generation potential (SGP) defined by Gray (1975), and computed from the ensemble mean of 14 climate of the 20th century (C20C) simulations with the NSIPP-1 AGCM forced with observed SSTs. For the Atlantic the SGP is computed for the area (10 - 20 N and 80 - 20 W). For the Pacific the SGP and storm counts are computed for the region (135E to 180E).

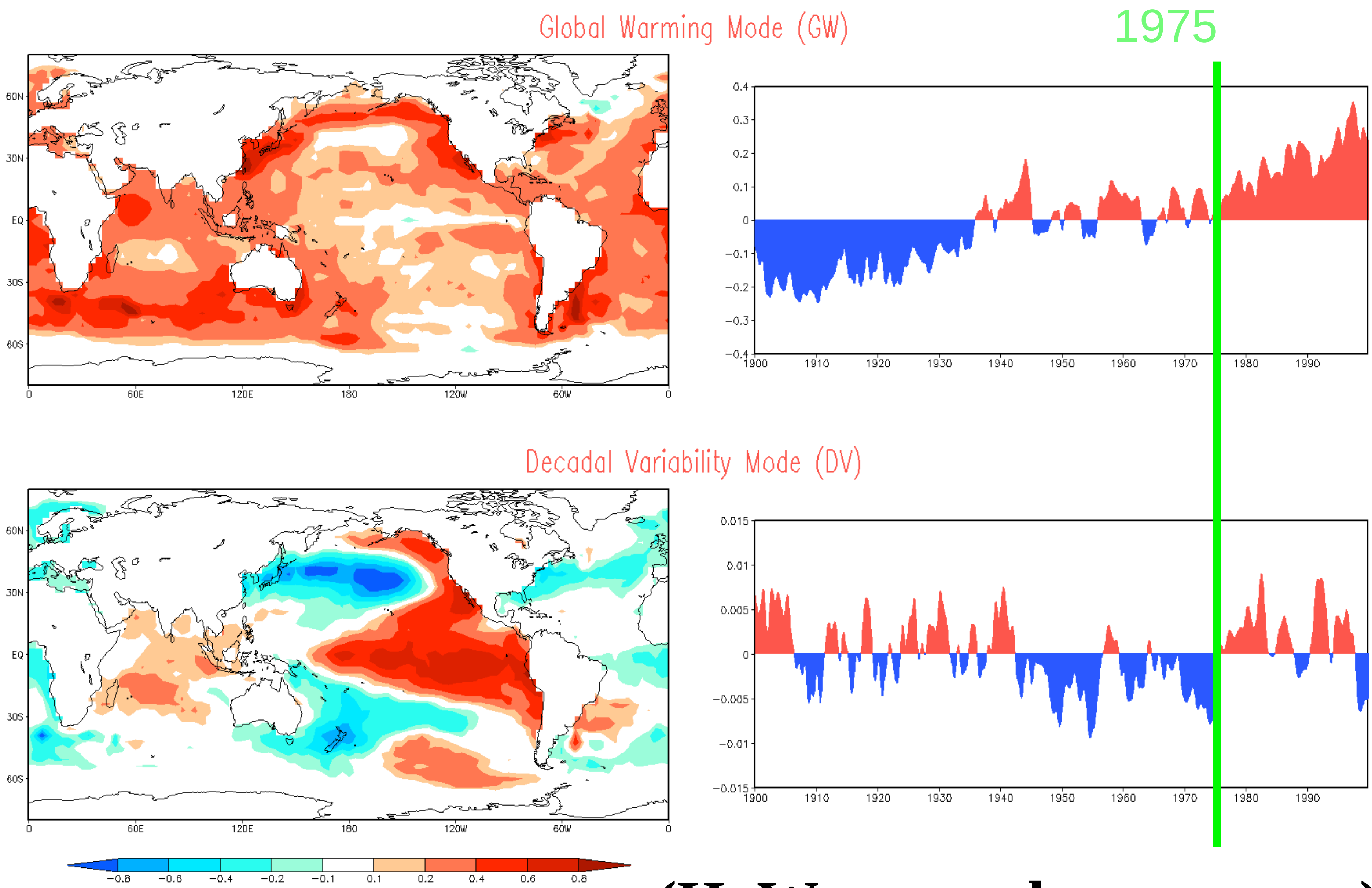




Decadal Variability

Example 4:
Trends, Climate Shifts

Global Warming (GW) and Decadal Variability (DV) modes
Hadley SST



(H. Wang et al - see poster)

Weather-Climate Link (Regional Climate Variability)

- Is complicated involving wide range of time and space scales and processes
  - Requires seamlessness?
  - Are these phenomena/processes captured by models?
  - Do we understand past behavior?

- Predictability depends on the extent to which any predictability in slow components is manifest at regional scales
  - Requires understanding the “pathways to predictability”
  - What components of the initial conditions, forcing matters (implications for observing system)?

Challenges

- Confronting models with observations:data assimilation (Ron Gelaro)
  - Improving how we use observations
  - weather versus climate (constraining processes)?
- Reanalysis (Mike Bosilovich)
  - Understanding and alleviating the impact of a changing observing system
  - Consistency across components
- OSSEs (Lars Peter Riishojgaard)
  - Developing a capability for weather
  - Looking toward climate applications

Challenges

What are our goals for prediction - weather, subseasonal, seasonal, interannual, decadal, trends, extreme weather events, droughts?

- Confronting models with observations:data assimilation
  - Improving how we use observations
  - weather versus climate (constraining processes)?
  - Model improvements and model validation
- Reanalysis
  - Understanding and alleviating the impact of a changing observing system
  - Consistency across components
  - Reducing uncertainties
- OSSEs
  - Developing a capability for weather
  - Looking toward climate applications

The End

Earth System Models and Data Assimilation

$$\partial x / \partial t = physical\ \ processes + \Delta x$$

Observed change

Model predicted change

Correction needed to keep model on track

For understanding processes and prediction:

-want Δx as small as possible (maximum use of all observations, high resolution, high accuracy, model encompasses all relevant components)

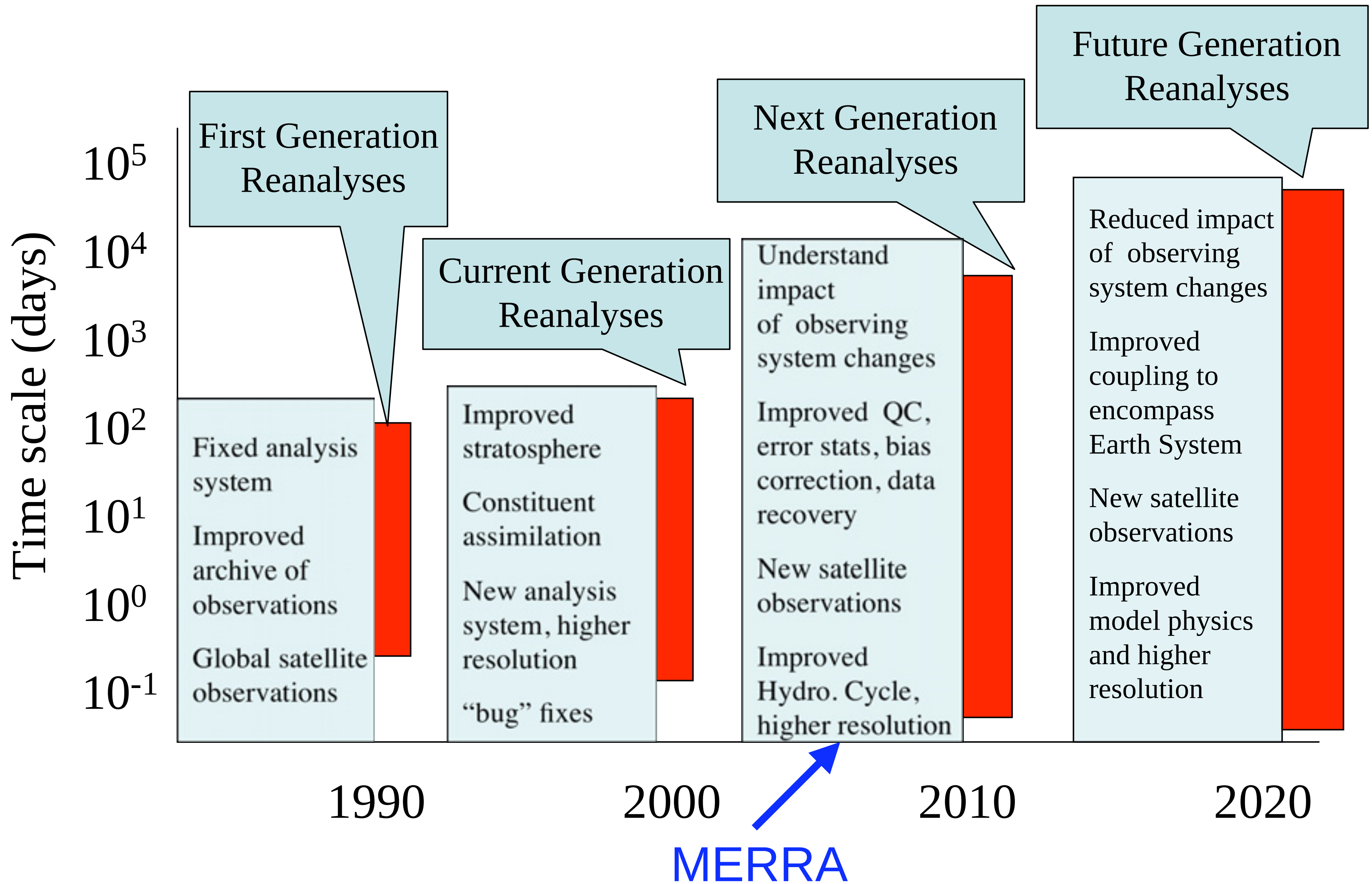
-improve use of observations (DAS development) and improve understanding of what observations are important for prediction (OSSEs)

For studying long-term climate variability:

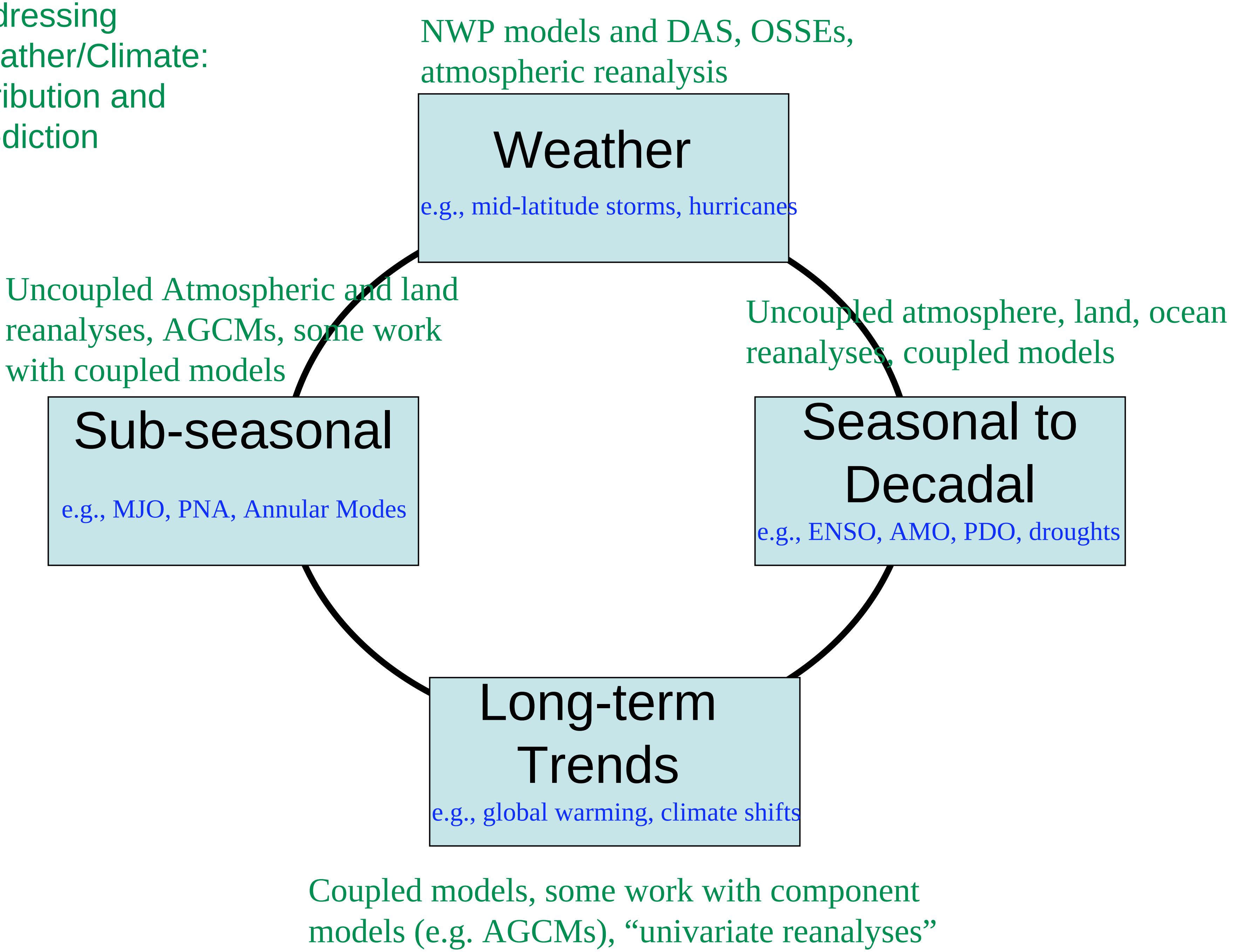
-give up small Δx for consistency in time

-bias correction, OSEs, reduced number of observations, DAS geared to maximizing use of sparse observations

Global Climate Data Assimilation

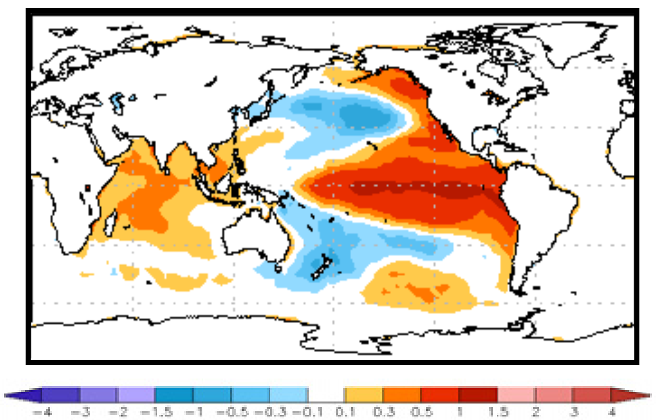


Current Tools for Addressing Weather/Climate: Attribution and Prediction



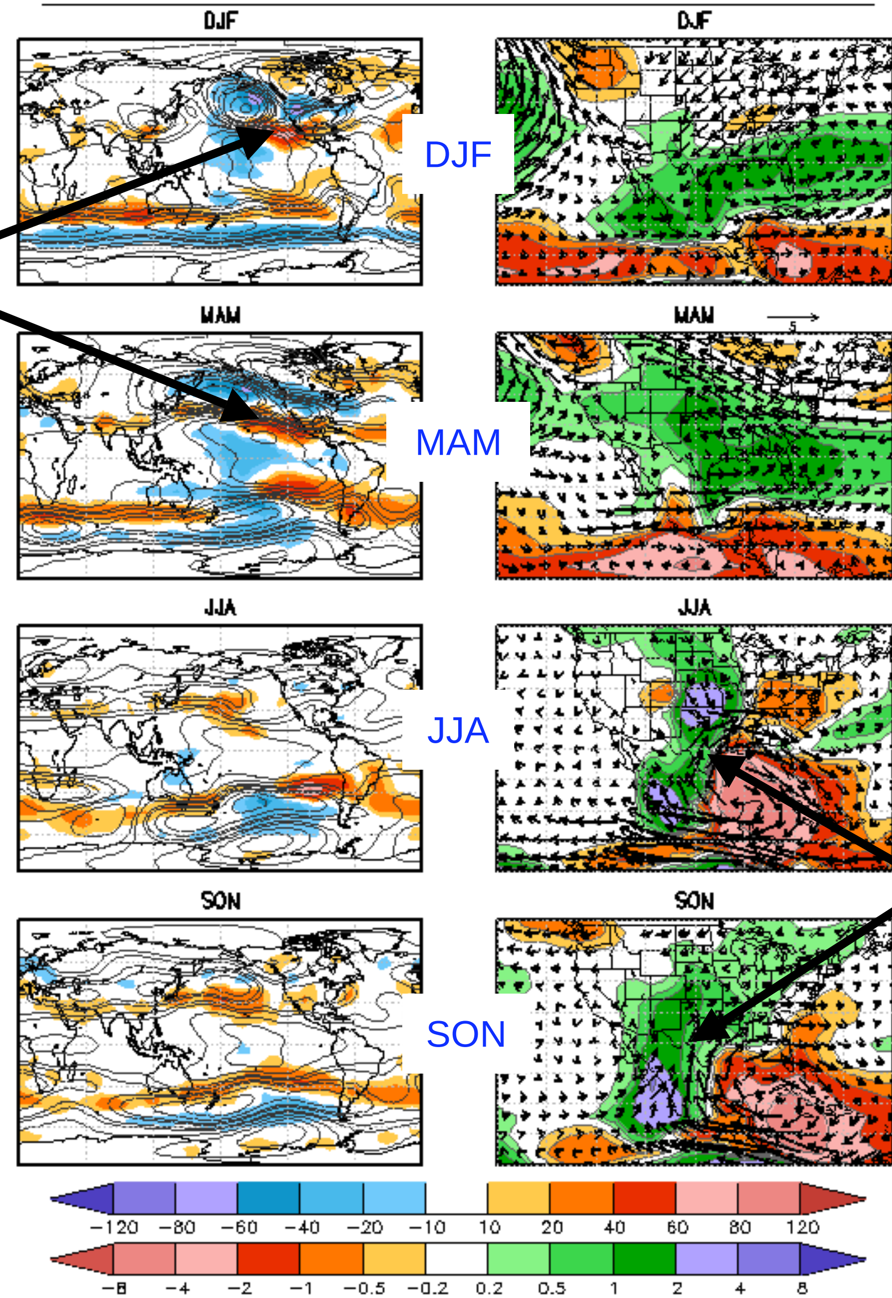
Seasonality in the Response to Constant SST forcing

Shift in storm tracks



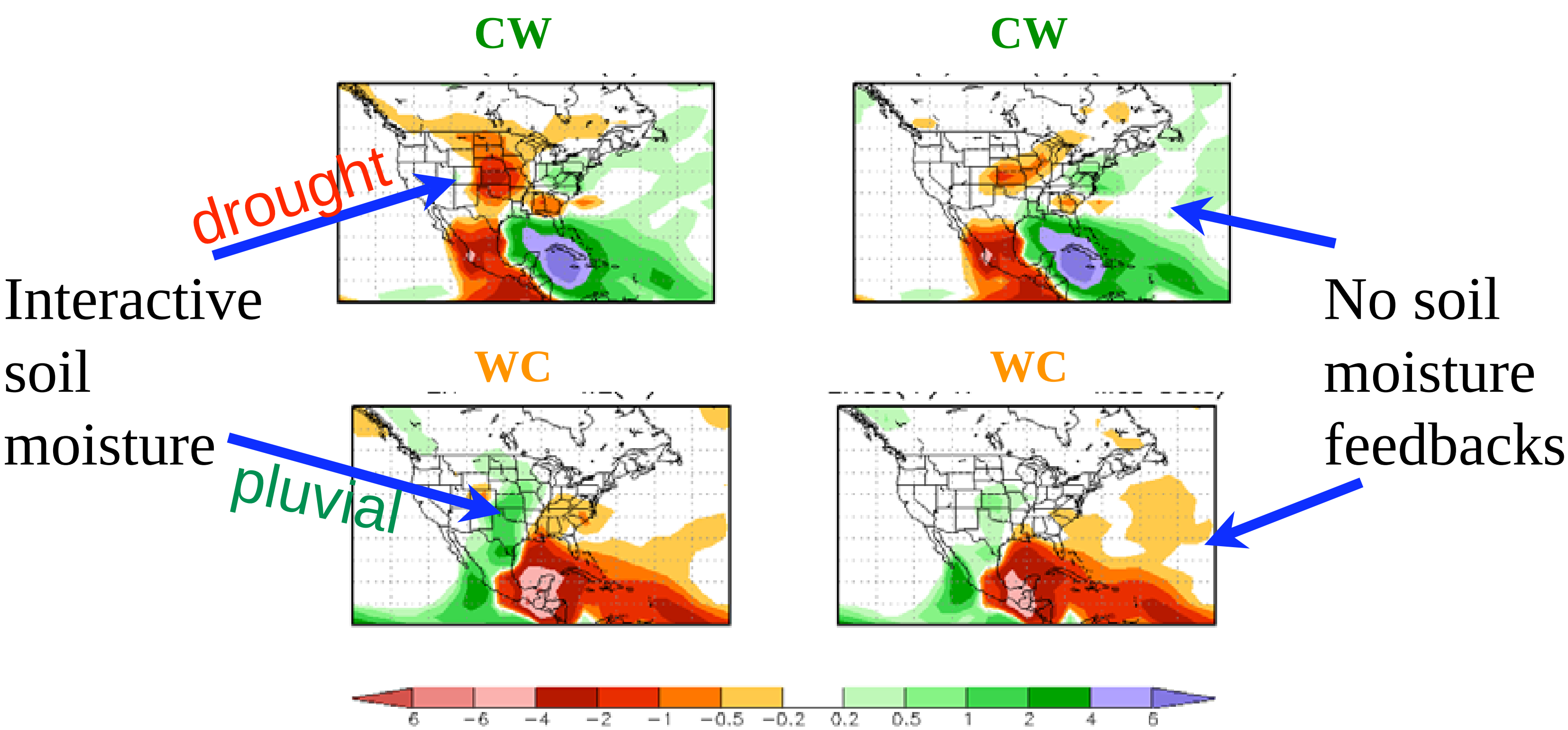
SST forcing

v'2 850 and Z200 V 850 and Precip



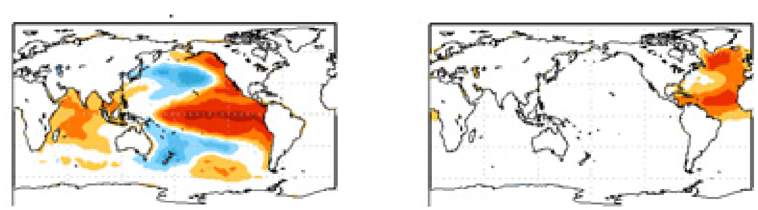
Change in LLJ

Impact of Different Ocean Basins and Soil Moisture Feedbacks on JJA Precipitation



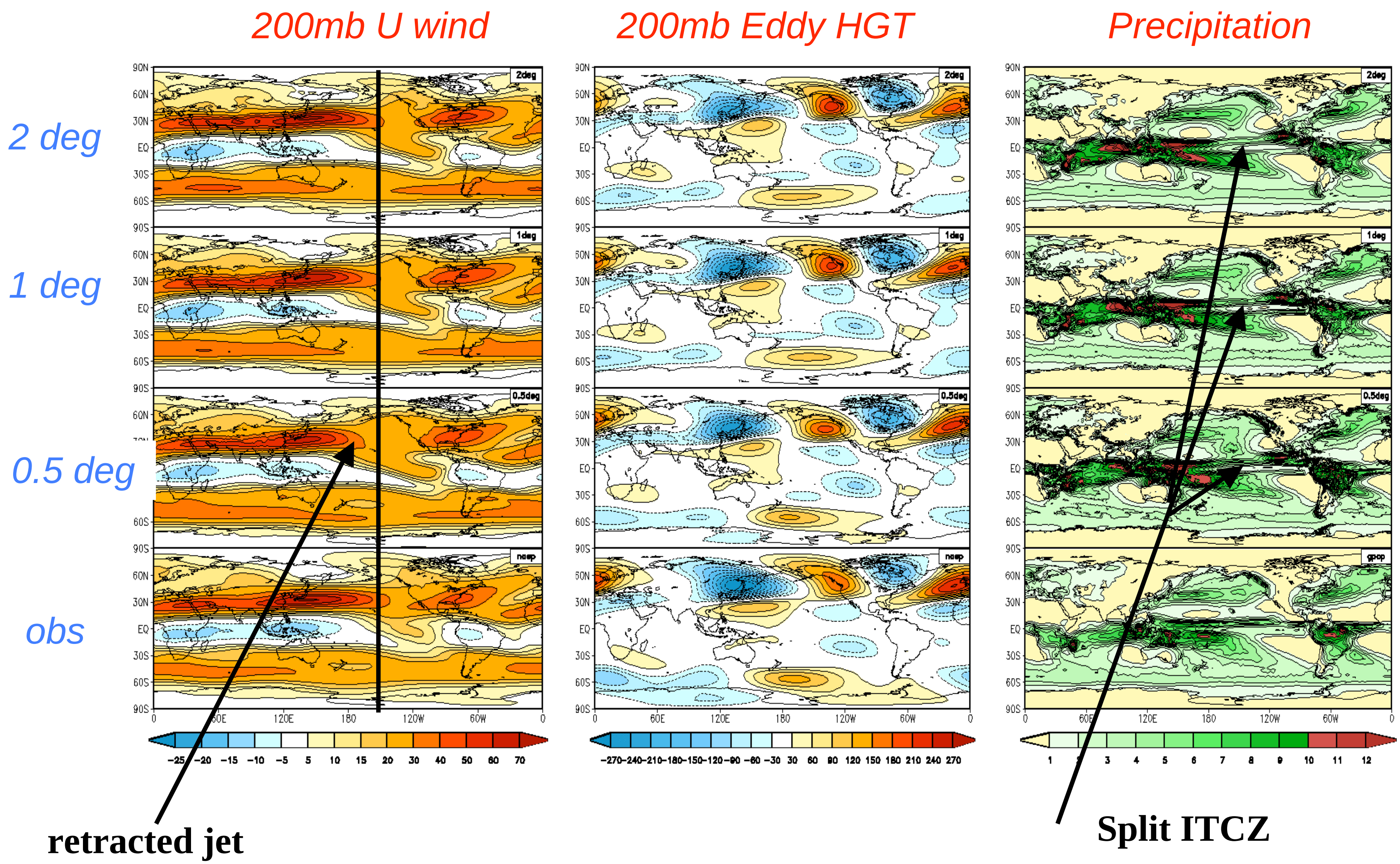
CW: cold Pacific, warm Atlantic

WC: warm Pacific, cold Atlantic

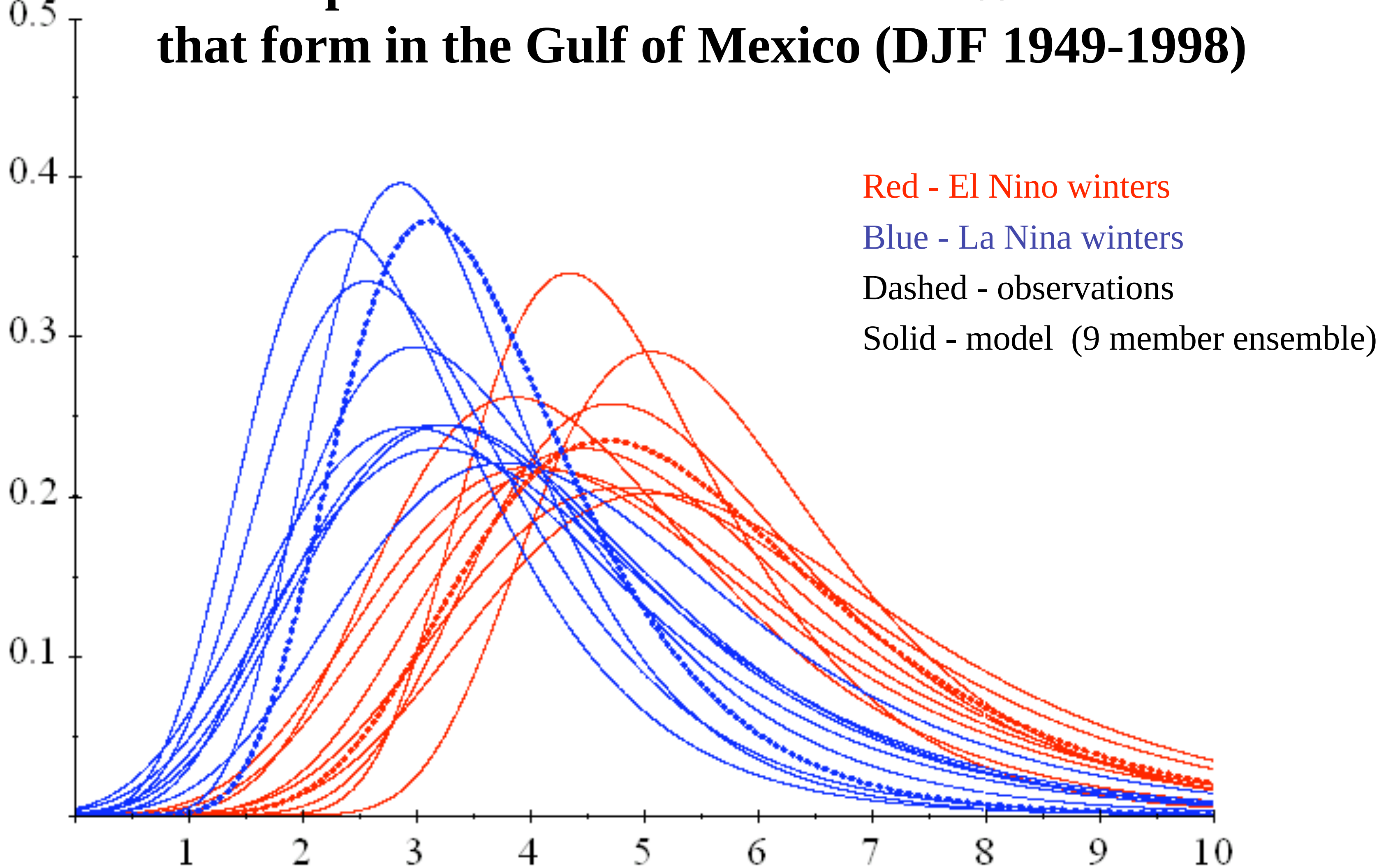


Y. Chang et al.

NSIPP AGCM Climatology (JFM)



ENSO Impact on the PDF of Extreme Winter Storms that form in the Gulf of Mexico (DJF 1949-1998)



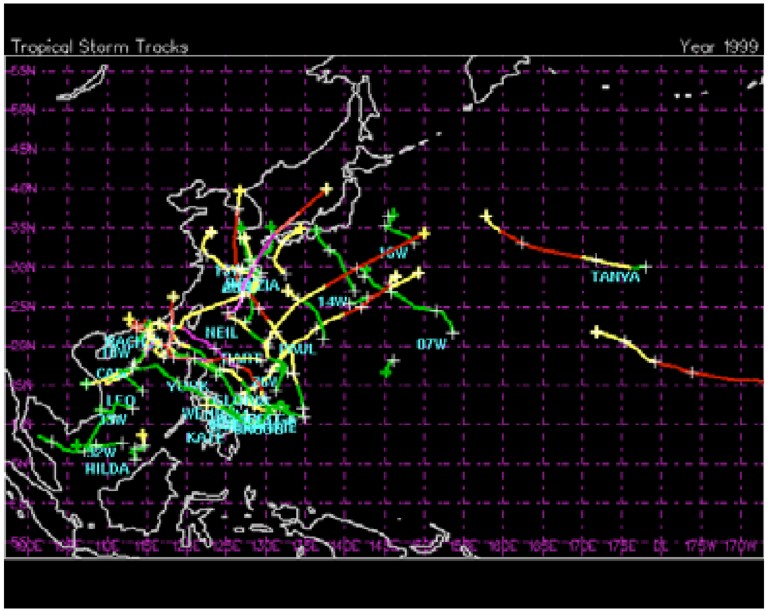
Maximum value of the principal components associated with EOF 3 (observations) and EOF 6 (model). Values are scaled so that the model and observed EOFs have the same total variance. Units are arbitrary. The PDFs are the fits to a Gumbel Distribution.

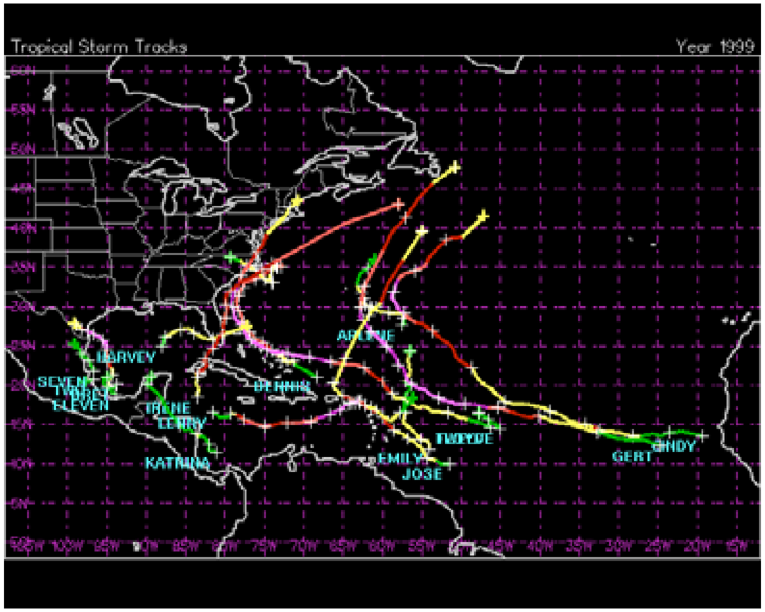
Interannual Variability

West Pacific and Atlantic storm tracks for selected years. Green: tropical depression, yellow: tropical storm, red/violet: hurricane/typhoon.

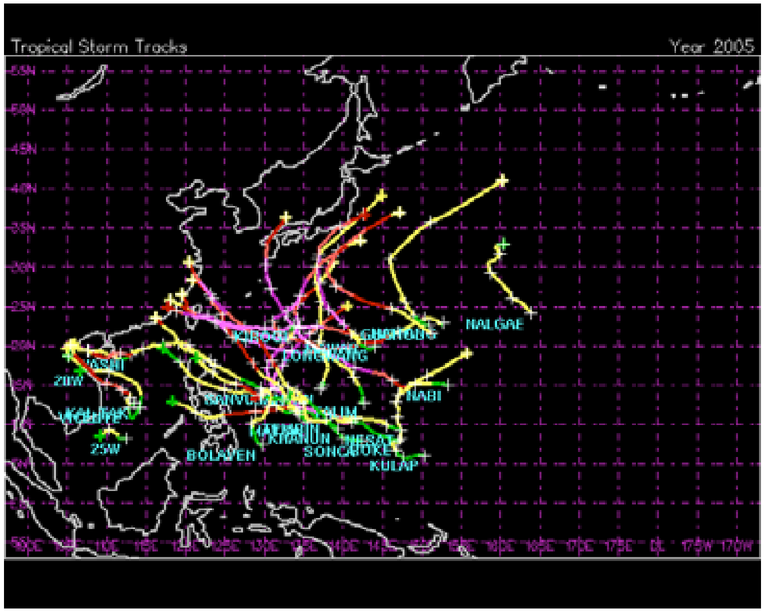
http://weather.unisys.com/hurricane/index.html

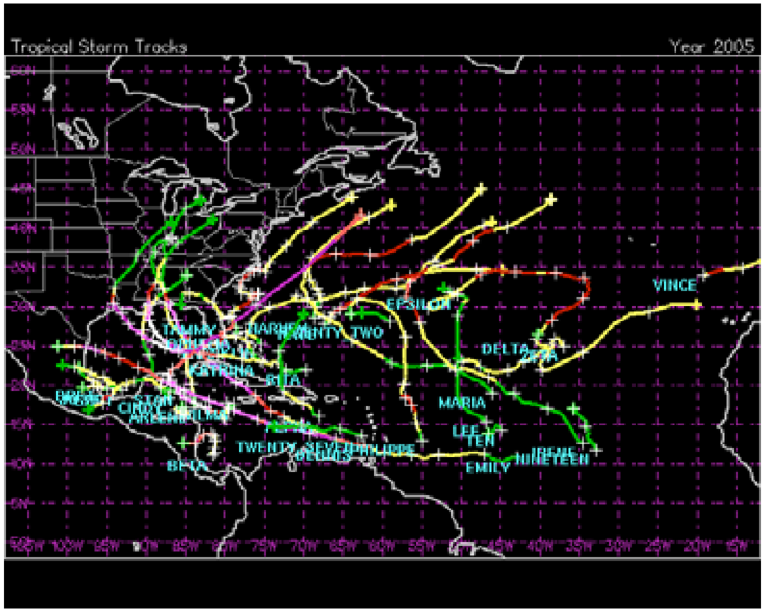
1999



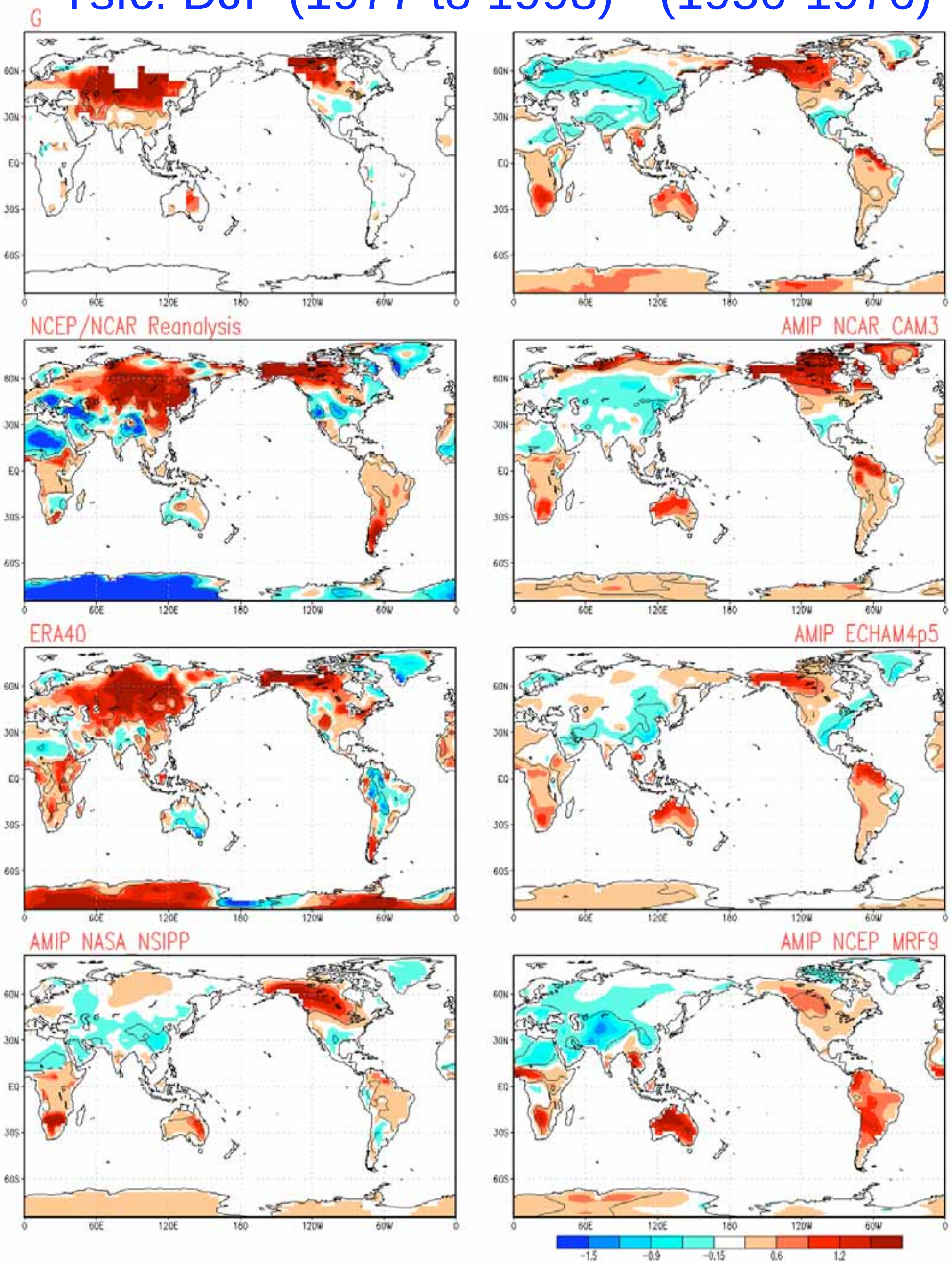


2005





Tsfc: DJF (1977 to 1998) - (1950-1976)



GHCN obs

AMIP GFDL/AM2

NCEP/NCAR reanalysis

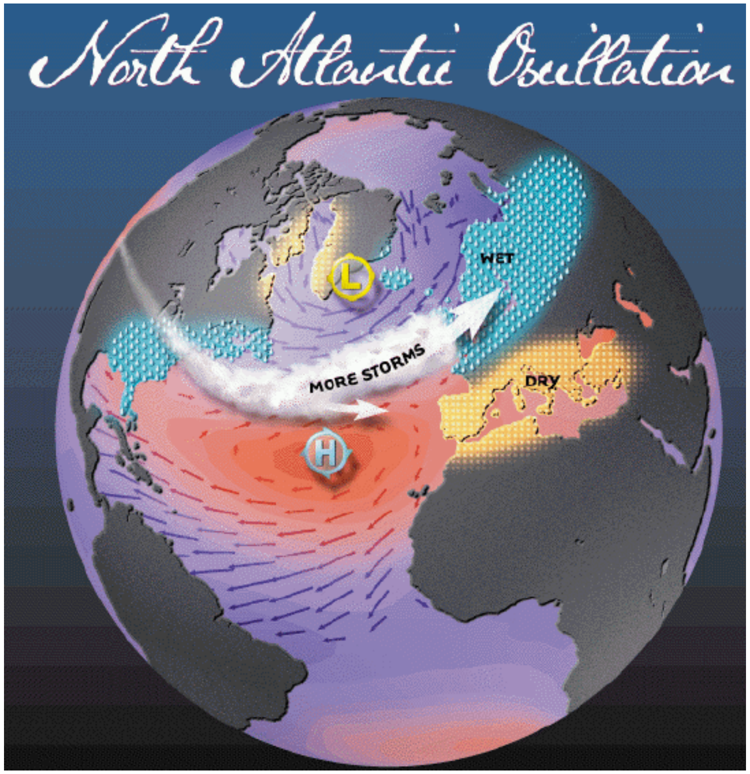
AMIP NCAR/CAM3

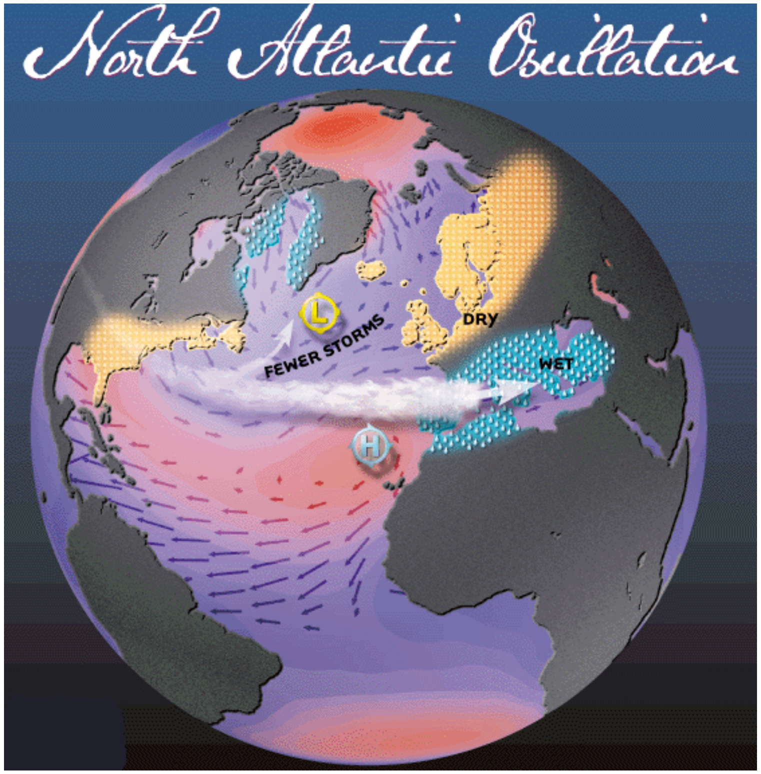
ERA40

AMIP ECHAM4p5

AMIP NASA/NSIPP

AMIP NCEP/MRF9

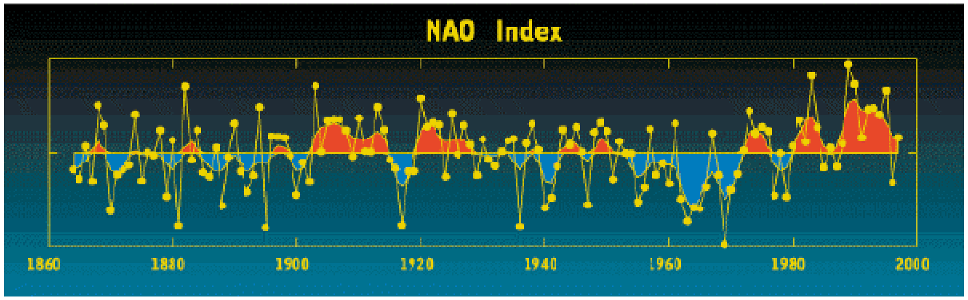




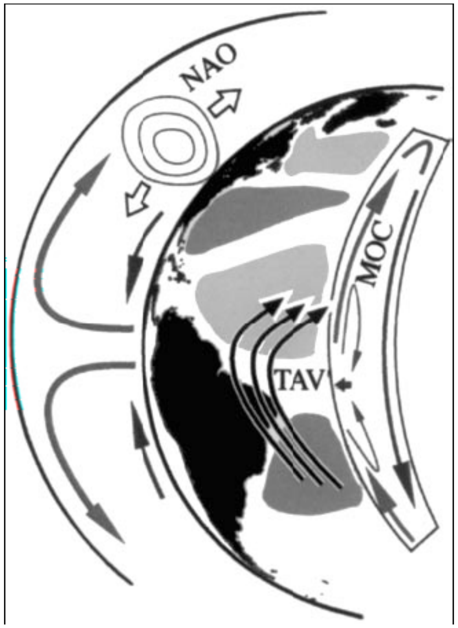
•The Positive NAO index phase shows a stronger than usual subtropical high pressure center and a deeper than normal Icelandic low.
•The increased pressure difference results in more and stronger winter storms crossing the Atlantic Ocean on a more northerly track.
•This results in warm and wet winters in Europe and in cold and dry winters in northern Canada and Greenland
•The eastern US experiences mild and wet winter conditions

•The negative NAO index phase shows a weak subtropical high and a weak Icelandic low.
•The reduced pressure gradient results in fewer and weaker winter storms crossing on a more west-east pathway.
•They bring moist air into the Mediterranean and cold air to northern Europe
•The US east coast experiences more cold air outbreaks and hence snowy weather conditions.
•Greenland, however, will have milder winter temperatures.

source: http://www.ldeo.columbia.edu/NAO by Martin Visbeck

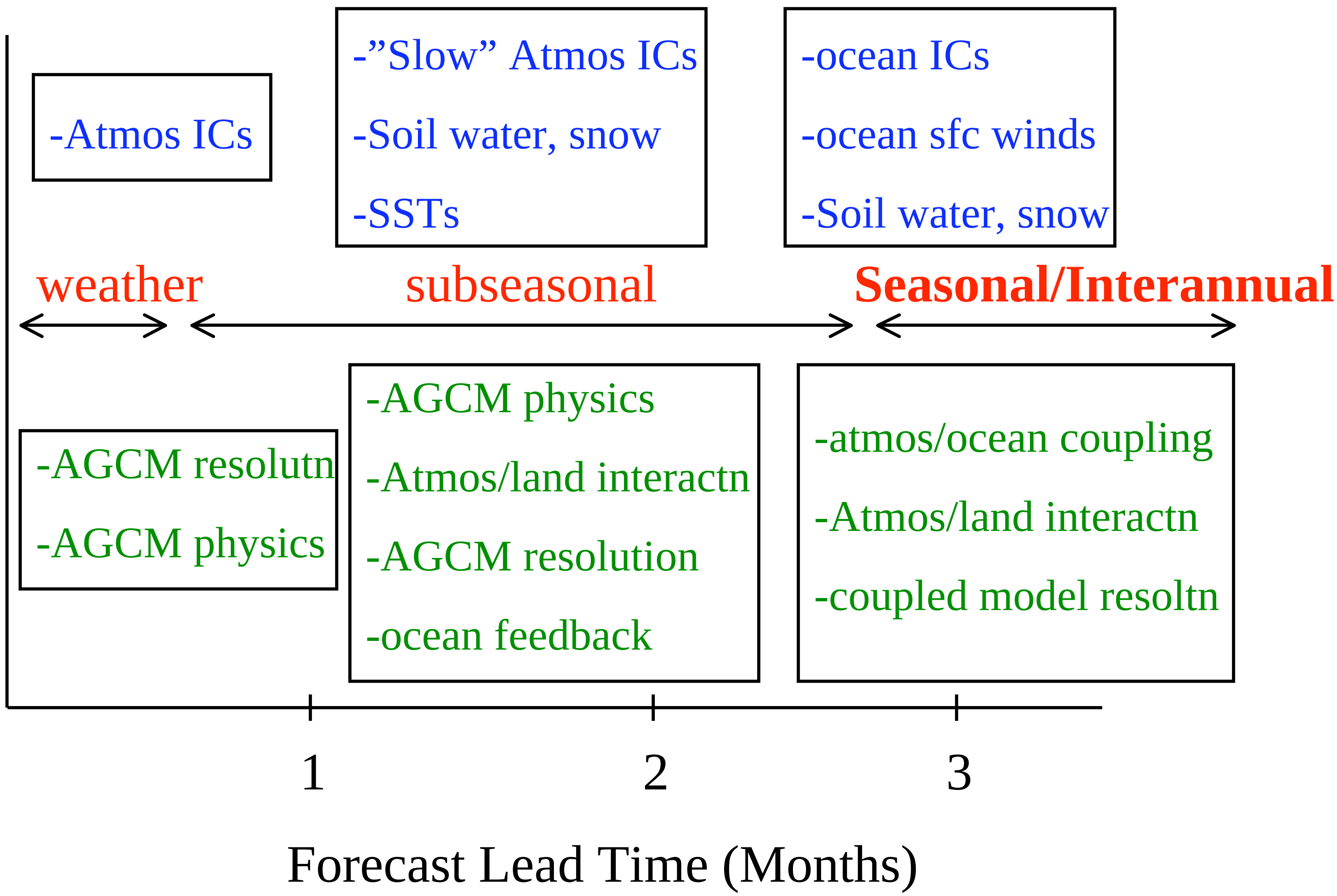


The winter NAO index is defined as the anomalous difference between the polar low and the subtropical high during the winter season (December through March). Source: http://www.ldeo.columbia.edu/NAO by Martin Visbeck



A schematic of TAV NAO MOC interactions. The strength of the coupling between the NAO and the stratosphere above and the ocean below is not yet clear. From Marshall et al. 2001

Observational and Modeling Priorities



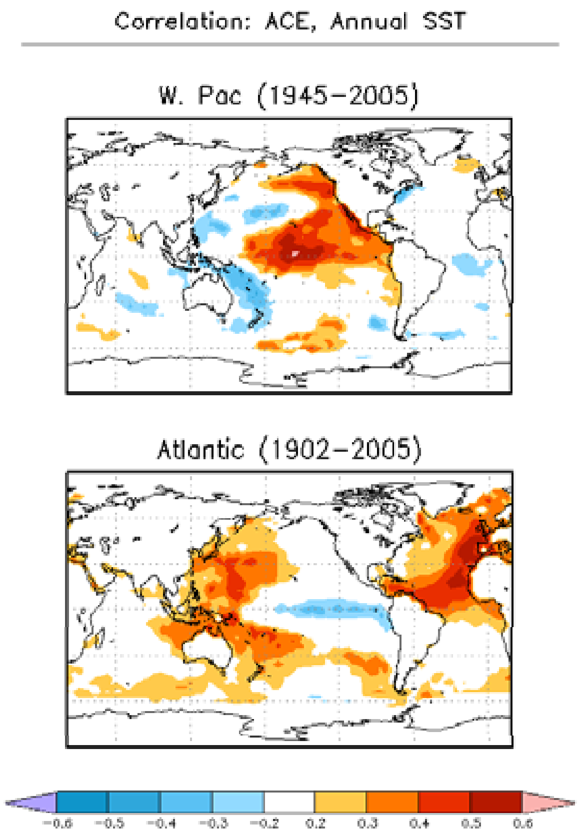
Challenges for Seasonal-to-Interannual Prediction

- ENSO
  - More realistic ENSO variability in coupled models
  - Improved regional response (tropical/extratropical connections, land surface feedbacks)
  - Realistic interactions with weather and other subseasonal variability (weather resolving climate models)

- Sources of predictability beyond ENSO
  - Atlantic Ocean, western hemisphere warm pool
  - Indo-Pacific SST
  - Role of (deep) soil moisture (year-to-year memory?)

- Improved initial conditions, verification data
  - ocean reanalyses
  - Atmospheric/land reanalyses (hydrological cycle, precipitation, clouds)

Correlation between accumulated cyclone energy (ACE) and annual mean SST for the West Pacific and Atlantic basins.



Link to SST

Challenges for Subseasonal Prediction

- Models must do many things right
  - Improved tropical/extratropical interactions, MJO
  - Soil moisture feedbacks
  - Extratropical atmos. variability (PNA, NAO, annular modes)
  - Interactions with weather (extremes), blocking, stratosphere
  - Intra-ensemble variability (predictability)
- Improved initial conditions
  - Improved hydrological cycle, precipitation, clouds
  - Soil moisture/snow observations to initialize land
  - Improved long-term reanalyses for ICs and verification
- Impact/role of SST not well quantified
- Requires large ensembles and high resolution
  - goal is to run fully coupled system (**evolve PDF from weather to seasonal and longer time scales**)